KINK method of determining spontaneous magnetostriction of ferro- and ferrimagnetic materials

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We show within the framework of the molecular field theory that temperature independent magnetostriction can be observed near the Curie temperature of ferromagnetic materials in weak magnetic fields. Experimental confirmation of this effect is given by using nickel and it is shown that this effect can be used to determine spontaneous magnetostriction.

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Without dwelling on the difficulty of determining the spontaneous linear magnetostriction λ_s and without analyzing the present-day methods of determining λ_s,[1-3] whose deficiencies are well known, we shall examine the possibility of experimental determination of λ_s on the basis of the KINK effect for magnetization.[4,5] According

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to the ideas developed in Refs. 4 and 5, an isotropic ferromagnet in weak magnetic fields $H < H_d$ (H_d is the demagnetizing field) undergoes a second-order phase transition (PT) of the order-order type at a temperature

$$\tau_t = 1 - \frac{1}{3}(h/d)^2, \tag{1}$$

where $\tau = T/T_C$, $h = H/\gamma\mu_0$, $d = N/\gamma$, T_C is the Curie temperature γ is the molecular field constant, μ_0 is the magnetic moment at 0 K, and N is the demagnetization factor, At $\tau \leqslant \tau_t$ the phase with nonuniform magnetization (NM) I_1 is stable

$$I_1 = \frac{\mu_1}{\mu_0} \operatorname{th}(I_1/\tau), \quad (\text{since} \quad H = H_d). \tag{2}$$

whereas in the region $\tau > \tau_t$ the minimum energy corresponds to the phase with uniform magnetization (UM) I_2

$$I_2 = \frac{\mu_2}{\mu_0} \operatorname{th}\left(\frac{h - dI_2 + I_2}{\tau}\right). \tag{3}$$

Thus, a transition from the NM phase to the UM phase is realized when the following condition is fulfilled

$$I_1 = I_2 = I_s = h/d, \tag{4}$$

which produces a temperature-invariant magnetization in the NM phase (I_s is the spontaneous magnetization). This idea evidently can be used to describe the behavior of different physical parameters that depend on magnetization, and, in particular, for magnetostriction.

In an isotropic ferromagnet in weak magnetic fields λ_s near T_c depends on the change in the direction of I_s; hence, the effects associated with variation of the absolute value of I can be disregarded. In this approximation the magnetoelastic energy near T_c can be written in the form [6]

$$F_{1,2} = -a\lambda_s \sigma_{1,2}(I_{1,2}/I_s)^2. \tag{5}$$

Here the indices 1 and 2 refer to the NM and UM phases, respectively, I_1 and I_2 are determined by the expressions (2) and (3), $\sigma_{1,2}$ are the average elastic stresses caused by magnetostrictive strain, and a is a constant that depends on the accepted unstrained state. If the magnetoelastic energy (5) is taken into account, then the PT can occur only if $F_1 = F_2$. Thus, we obtain from Eqs. (4) and (5) the equality $\lambda_1 = \lambda_2 = a\lambda_s$ at $\tau = \tau_t$. In the examined approximation of the magnetoelastic energy quadratic with respect to magnetization λ_s is determined by the expressions

$$\lambda_1 = a\frac{\lambda_s}{I_s^2}\left(\frac{h}{a}\right)^2 \tag{6}$$

$$\lambda_2 = \frac{a\lambda_s}{I_s^2} \operatorname{th}^2\left(\frac{h - dI_2 + I_2}{\tau}\right) \tag{7}$$

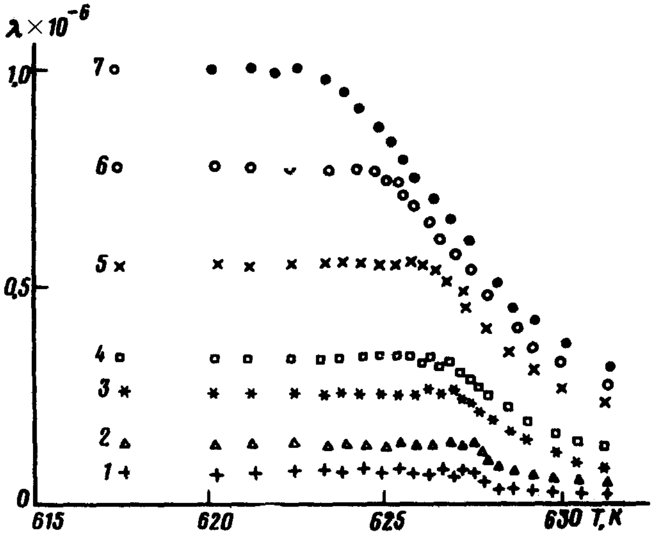

FIG. 1. Temperature dependence of the magnetostriction of Ni in different magnetic fields : 1, 60 Oe; 2, 150 Oe; 3, 200 Oe; 4, 250 Oe; 5, 300 Oe; 6, 350 Oe; 7, 400 Oe.

for the NM and UM phases, respectively.

Thus, in the samples of ferro- and ferrimagnetic materials with a large demagnetization factor λ, in weak fields $H < H_d$, has the following peculiarities: 1) λ is independent of T in nonuniformly magnetized phase and depends quadratically on H_{ext} [see Eq. (6)]; 2) the values of λ corresponding to τ_t determine the temperature dependence of λ_s near T_C.

To confirm experimentally the indicated peculiarities, we measured λ in polycrystalline nickel (99.99%). The investigated sample had the shape of an elliptic plate whose demagnetization factors along the axes of the ellipse were $N_a = N_b = 4.97$. Using a capacitive dilatometer with a sensitivity of better than 10^{-8}, we recorded more than 50 isotherms in the neighborhood of T_C. The temperature stability for

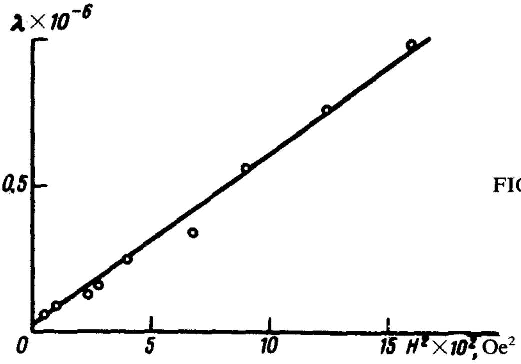

FIG. 2. Dependence of λ on H^2 near T_C of nickel.

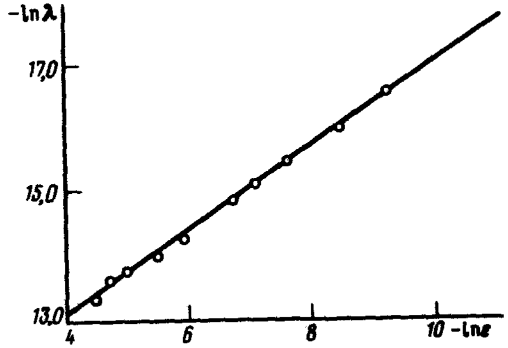

FIG. 3. Temperaure dependence of λ_s in the log-log scale.

recording of the isotherms was better than 0.01°. Since near T_C the magnetocaloric effect has a considerable influence on λ, we took measures to eliminate this effect.

The presence of a kink effect in magnetostriction was confirmed by measurements in up to 400-Oe fields. In fact, as seen in Fig. 1 which show the curves for the temperature dependence of λ in different magnetic fields, which were reconstructed from the isotherms, λ remains constant in the temperature region $T < T_t$ (within the limits of experimental error of 1%). At $T = T_t$ the curve $\lambda = f(T)$ has a break (a kink) whose temperature T_t, according to Eq. (1), is shifted in the direction of low temperatures with increasing H. Moreover, the quadratic dependence of λ on H, which follows from Eq. (6), was confirmed experimentally for the temperatures $T < T_t$ (see Fig. 2).

The temperature dependence of λ_s, which was determined from the values corresponding to the breaks on the curve $\lambda = f(T)$ in different magnetic fields, is described well in the temperature range $10^{-4} < \epsilon = (T_C - T)/T_C < 10^{-2}$ by the following power law:

$$\lambda_s = A\epsilon^x. \qquad (8)$$

In Fig. 3 this dependence is described in a log-log scale; the solid line corresponds to Eq. (8), with a critical index $x = 0.67 \pm 0.02$, and the points correspond to the experimental data. The obtained value x satisfies the relation $x = 2\beta$ (β is the critical magnetization index), which follows from magnetostriction theory.[1,3]

As a result of measuring the magnetostriction in fields $H < H_d$, we can also estimate T_C and β from Eq. (1) by using the graphic representation of the experimental data in the coordinates: H^2 and T_t—if T_C and H^2 are defined and $T_C - T_t$ if β is defined. The values $T_C = 627.75$ K and $\beta = 0.335$ determined by this method are in satisfactory agreement with the data obtained by direct measurements.[7]

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